Computing Low-Flow Statistics for Ungaged Locations on Pennsylvania Streams By Use of Drainage-Area Ratios

Introduction

The U.S. Geological Survey (USGS), in cooperation with the Pennsylvania Department of Environmental Protection (PaDEP), developed low-flow statistics for approximately 2,800 ungaged locations on streams in Pennsylvania by use of streamflow statistics from streamflow-gaging stations and drainage-area ratios ranging from one-third to three times. These low-flow statistics will aid PaDEP in reviewing requests for permits associated with stream-water withdrawals from, and effluent discharges to, Pennsylvania streams.

Methodology

Low-flow statistics from 312 USGS streamflow-gaging stations (gages) were computed as described in Ehlke and Reed (1999). The gages used in the computations were active and discontinued stations with at least 10 years of continuous record and were representative of the hydrologic conditions encountered throughout Pennsylvania. The computed low-flow statistics include the **1-day 10-year low flow ($Q_{1,10}$)**, **7-day 10-year low flow ($Q_{7,10}$)**, **30-day 10-year low flow ($Q_{30,10}$)**, **mean**, **median**, **harmonic mean**, and **flow-duration table**.

Regulation and diversion of streamflow can significantly modify low-flow discharges. Large reservoirs are often required to release a predetermined amount of water to supplement streamflow during droughts; diversions can decrease streamflow during droughts. Occasionally, these withdrawals are discharged to different stream basin, increasing the streamflow in the discharge basin. Regulation is defined for this website as a stream with an upstream flood-control reservoir(s) which controls 10 percent or more of the contributing basin. If regulation began while the gage was in operation, records were analyzed for pre-regulation, post-regulation, and entire period of record streamflow conditions. In the case of multiple upstream reservoirs controlling the streamflow, the year in which the reservoir was built that makes the cumulative controlled area equal to 10 percent determines the break in record. Because diversions are more difficult to quantify and are not always published, basin with diversion of streamflow were analyzed the same as a basin without any diversion.

The low-flow statistics presented in this web application were transferred upstream to one-third and downstream to three times the drainage area of a nearby, hydrologically similar gage. While statistics were computed for pre-regulation, post-regulation and the entire period of record for gages with upstream regulation, only the post-regulation conditions are transferred to bridges. To transfer either pre-regulation or entire period statistics to sites upstream and downstream based on drainage area ratios, follow the example shown below.

Example. Transfer the $Q_{7,10}$ computed from pre-regulation conditions from gage 01541500 on Clearfield Creek to a site upstream with a drainage area of 194 mi^2. The drainage area at the gage is 371 mi^2 and the $Q_{7,10}$ is 21 ft^3/s.

1 Determine the drainage area (DA) ratio:

$DA_{site} / DA_{gage} = 194 / 371 = 0.52$

2. Multiply the calculated ratio times the low-flow statistic at the gage:

$0.52 * 21 = 11\ ft^3/s$

The period of record for a gage can also influence computed low-flow statistics. Short period of records which include one or more droughts can result in a lowered low-flow statistic. A gage which was operated for a short period during wet conditions, with the absence of any drought periods, can have associated elevated low-flow statistics. A gage should ideally have a period of record which contains both normal and drought conditions extended throughout a long period of time. The period of record shown for each gage in the website application should be inspected to ensure that the computed low-flow statistic is applicable to the specified needs of the user.

Low-flow statistics from gages were transferred to approximately 2,700 hydrologically similar (including streams affected by carbonate bedrock, mining, and regulation) ungaged locations upstream and downstream from the gages on the basis of drainage-area ratios (ratios). To determine a ratio range appropriate for transferring low-flow statistics, the $Q_{7,10}$ statistics from 74 gages reported by Ehlke and Reed (1999) were compared. To maximize the number of applicable paired gages used in the analysis, some gages were used in multiple paired comparisons. This analysis produced 92 comparisons from 46 paired gages that are hydrologically similar and have ratios ranging from 0.24 to 4.2 times.

Low-flow regionalization was last done in Pennsylvania by the USGS in 1982. Flippo (1982b) presented 12 regional regression equations for estimating $Q_{7,10}$ statistics at ungaged locations in Pennsylvania and reported that two-thirds of the regression estimates were expected to be within standard errors of estimate, that range from 20 to 45 percent (Flippo, 1982a, 1982b). For this study, the $Q_{7,10}$ statistic and the median standard error of estimate from Flippo (1982b), 33 percent, were selected as analysis tools for testing the transferred statistics.The $Q_{7,10}$ statistic was chosen as the representative statistic because it is the only commonly used low-flow statistic the regression equations predict.

Results of the analyses are listed in table 1 and shown in figures 1, 2, and 3. Included in table 1 for each paired comparison are the gage numbers, periods of record by **climatic year**, drainage areas, drainage-area ratios, the $Q_{7,10}$ statistics reported in Ehlke and Reed (1999), the transferred $Q_{7,10}$ statistics that use the ratios, and the absolute percent differences between the reported and the transferred $Q_{7,10}$ statistics. The largest absolute percent difference, 125 percent, is at a 1.8 ratio, and the smallest percent difference, 0.29 percent, is at a 0.41 ratio (table 1).

The relation between ratio and absolute percent difference for the 92 comparisons is shown in figure 1. Vertical solid and dashed lines are superimposed at ratio ranges of one-third to three times and one-half to two times, respectively. The median standard error of estimate for regression from Flippo (1982b), 33 percent, is superimposed as a horizontal dashed line for validity testing. Of the 76 comparisons that fall within the ratio range of one-third to three times, 62, or 82 percent, have absolute percent differences less than or equal to the median standard error of estimate for regression. Of the 64 comparisons that fall within the ratio range of one-half to two times, 53, or 83 percent, have absolute percent differences less than or equal to the median standard error of estimate for regression. Extending the range from one-half to two times to one-third to three times results in 12 additional sites, 9 of which have absolute percent differences less than or equal to the median standard error of estimate for regression. The median absolute percent difference for both the one-third to three times ratio and the one-half to two times ratio ranges is 14 percent, which is lower than the median standard error of estimate for regression from Flippo (1982b). Of the 16 comparisons that fall outside the one-third to three times ratio, only 3, or 19 percent, have absolute percent differences less than the median standard error of estimate for regression.

A comparison between the computed $Q_{7,10}$ statistics as reported in Ehlke and Reed (1999) and the 76 transferred $Q_{7,10}$ statistics that are within the one-third to three times ratio is shown in figure 2. The greatest outlier occurs at 3,210 ft^3/s, with a transferred $Q_{7,10}$ equalling 2,110 ft^3/s (fig. 2). An analysis of the relation between absolute percent difference and drainage area, not included herein, revealed no bias.

The relation between the absolute percent difference and the gage period of record for the 76 transferred $Q_{7,10}$ statistics that are within the one-third to three times ratio is shown in figure 3. Vertical dashed lines are superimposed at 20 and 40 years of record, and the median standard error of estimate for regression from Flippo (1982b), 33 percent, is superimposed as a horizontal dashed line. Of the 33 gages with less than 20 years of record, 8, or 24 percent, have absolute percent differences that exceed the median standard error of estimate for regression. Of the 20 gages with periods of record between 20 and 40 years, 4, or 20 percent, have absolute percent differences that exceed the median standard error of estimate for regression. And of the 23 gages with more than 40 years of record, only 1, or 4 percent, has an absolute percent difference that exceeds the median standard error of estimate for regression.

Conclusions

While the analyses discussed herein do not categorically preclude the use of ratios outside the one-third to three times range to transfer computed low-flow statistics on hydrologically similar streams in Pennsylvania, they do suggest the one-third to three times ratio is as appropriate as a one-half to two times ratio as a maximum range. In addition, the validity tests discussed herein indicate that transferring low-flow statistics computed at long-term gages to hydrologically similar, upstream and downstream ungaged locations within a one-third to three times ratio range is as reliable as, if not more than, the regression equations developed by Flippo (1982b) to estimate $Q_{7,10}$. Because the $Q_{7,10}$ statistic is representative of what is often considered very low-flow conditions, the method discussed herein should produce similar results with other low-flow statistics.

Table 1. *Comparison of 7-day 10-year low-flow statistics ($Q_{7,10}$) with those developed using drainage-area ratios as a basis for transferring statistics upstream and downstream to hydrologically similar locations*

[climatic year, 12-month period from April 1 to March 31; mi^2, square miles; $Q_{7,10}$ statistics from Ehlke and Reed (1999); ft^3/s, cubic feet per second; transferred $Q_{7,10}$ values were computed using unrounded drainage-area ratios]

U.S. Geological Survey Stream-flow-gaging station	Period of record (climatic year)	Drainage area (mi^2)	Drainage-area ratio	$Q_{7,10}$ (ft^3/s)	Transferred $Q_{7,10}$ (ft^3/s)	Absolute value of percent difference
01440400	1959-96	65.9	0.25	7.54	12.4	64
01442500	1952-95	259	3.9	48.7	29.6	39
01447500	1945-96	91.7	.28	13.3	19.2	44
01448000	1918-59	322	3.5	67.4	46.7	31
01453000	1943-94	1,279	.94	358	491	37
01454700	1968-95	1,359	1.1	522	380	27
01465770	1966-81	5.08	.24	.44	.54	23
01465798	1967-94	21.4	4.2	2.26	1.85	18
01467042	1966-81	37.9	.76	9.29	9.89	6.5
01467048	1967-94	49.8	1.3	13.0	12.2	6.2
01467086	1967-88	16.6	.55	4.36	1.93	56
01467087	1984-94	30.4	1.8	3.55	7.98	125
01467086	1967-88	16.6	.49	4.36	3.23	26
01467089	1967-81	33.8	2.0	6.58	8.88	35
01467087	1984-94	30.4	.90	3.55	5.92	67
01467089	1967-81	33.8	1.1	6.58	3.95	40
01467500	1945-69	53.4	.40	17.1	17.7	3.5
01468500	1949-95	133	2.5	44.2	42.6	3.6
01470960	1967-78	175	.83	38.5	39.4	2.3
01471000	1952-79	211	1.2	47.5	46.4	2.3
01470960	1981-94	175	.83	31.3	36.2	16
01471000	1981-94	211	1.2	43.6	37.7	14
01471510	1979-95	880	.77	245	216	12
01472000	1935-96	1,147	1.3	281	319	14
01472198	1985-95	38.0	.25	7.39	3.60	51
01472500	1886-1913	152	4.0	14.4	29.6	106
01472500	1886-1913	152	.54	14.4	8.17	43
01473000	1916-55	279	1.8	15.0	26.4	76
01480300	1962-94	18.7	.41	3.39	3.38	.29
01480500	1945-94	45.8	2.4	8.27	8.30	.36
01480700	1975-96	60.6	.67	14.5	19.3	33
01480870	1975-94	89.9	1.5	28.6	21.5	25
01516350	1978-96	153	.54	9.79	4.73	52
01518000	1940-76	282	1.8	8.71	18.0	110
01518862	1985-95	90.6	.30	1.14	.64	44
01520000	1953-76	298	3.3	2.10	3.75	79
01531500	1915-95	7,797	.89	581	601	3.4

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01533400	1978-96	8,720	1.1	672	650	3.3
01531500	1915-95	7,797	.78	581	643	11
01536500	1900-96	9,960	1.3	821	742	9.6
01534500	1961-96	108	.33	18.0	11.5	36
01536000	1961-95	332	3.1	35.2	55.3	57
01536500	1900-96	9,960	.89	821	898	9.4
01540500	1906-96	11,200	1.1	1,010	923	8.6
01536500	1981-96	9,960	.41	874	1,326	52
01570500	1981-96	24,100	2.4	3,210	2,110	34
01541200	1967-95	367	.77	43.6	45.5	4.4
01541303	1980-95	474	1.3	58.8	56.3	4.3
01546400	1985-95	58.5	.67	15.0	19.3	29
01546500	1942-94	87.2	1.5	28.7	22.4	22
01547200	1957-96	265	.78	99.9	75.0	25
01547500	1956-70	339	1.3	96.0	128	33
01548500	1919-95	604	.81	23.8	26.4	11
01549000	1910-20	750	1.2	32.8	29.6	9.8
01548500	1919-95	604	.64	23.8	24.2	1.7
01549700	1962-95	944	1.6	37.9	37.2	1.8
01551500	1958-95	5,682	.83	584	604	3.4
01553500	1962-95	6,847	1.2	728	704	3.3
01554000	1981-95	18,300	1.6	2,150	1,960	8.8
01540500	1981-95	11,220	.61	1,200	1,320	10
01554000	1981-96	18,300	.76	2,150	2,440	13
01570500	1981-96	24,100	1.3	3,210	2,830	12
01563500	1939-71	2,030	.61	241	222	7.9
01567000	1901-71	3,354	1.7	367	398	8.4
01570500	1892-1978	24,100	.93	2,530	2,510	.79
01576000	1933-96	25,990	1.1	2,710	2,730	.74
03016000	1943-96	3,660	.48	394	368	6.6
03031500	1934-95	7,671	2.1	772	826	7.0
03017500	1940-79	233	.50	16.4	12.2	26
03019000	1924-40	469	2.0	24.6	33.0	34
03020500	1934-96	300	.95	30.6	32.1	4.9
03021000	1911-32	315	1.0	33.7	32.1	4.7
03022500	1923-39	629	.63	31	45.6	47
03023500	1910-25	998	1.6	72.3	49.2	32

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03023500	1910-25	998	.97	72.3	60.2	17
03024000	1934-70	1,028	1.0	62.0	74.5	20
03028500	1954-94	204	.25	65.3	41.5	36
03029500	1954-96	807	4.0	164	258	57
03029000	1941-51	303	.38	25.3	21.6	15
03029500	1940-51	807	2.7	57.4	67.4	17
03029000	1941-51	303	.24	25.3	13.4	47
03031000	1943-53	1,246	4.1	55.1	104	89
03063000	1938-55	2,720	.62	290	286	1.4
03072500	1940-95	4,407	1.6	463	470	1.5
03072500	1940-95	4,407	.83	463	407	12
03075070	1935-95	5,340	1.2	494	561	14
03082500	1927-96	1,326	.77	209	244	17
03083500	1928-95	1,715	1.3	316	270	15
03100000	1913-22	152	.84	3.56	2.91	18
03102000	1921-32	181	1.2	3.47	4.24	22
03104000	1912-32	608	.77	14.7	12.5	15
03104500	1914-32	792	1.3	16.3	19.1	17

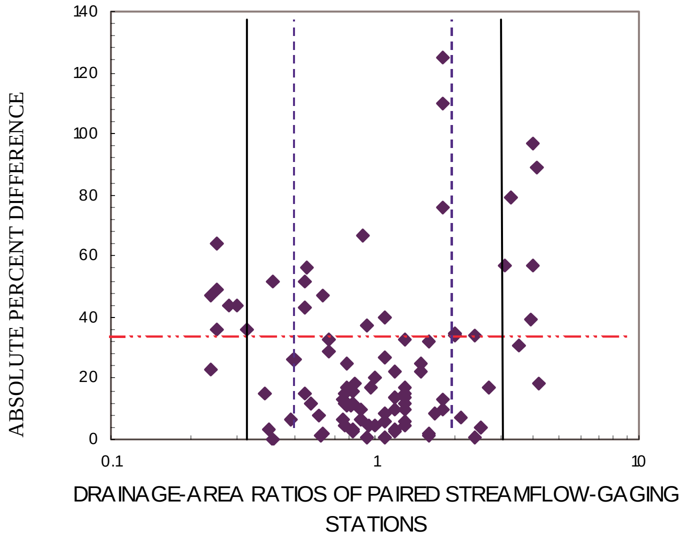

Figure 1.--Relation between drainage-area ratios and absolute percent differences for the streamflow-gaging stations (vertical, black solid lines encompass the one-third to three times ratio, vertical, blue dashed lines encompass the one-half to two times ratio, and horizontal red dashed line represents the median standard error of estimate for regression from Flippo, 1982b)

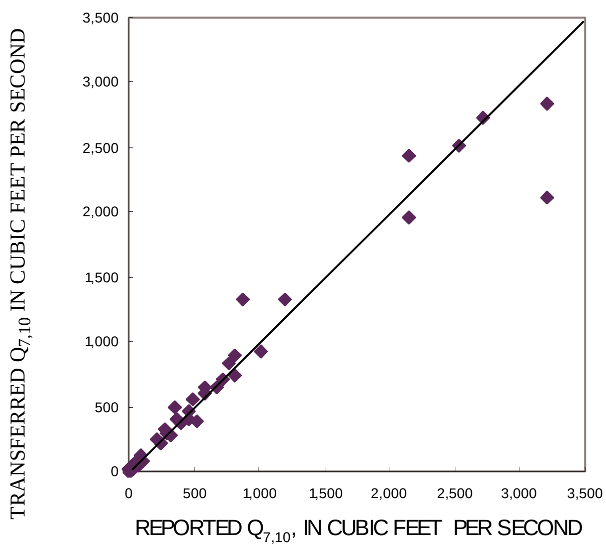

Figure 2.--Comparison between the $Q_{7,10}$ statistics reported in Ehlke and Reed (1999) and the corresponding transferred $Q_{7,10}$ statistics within the one-third to three times ratio range

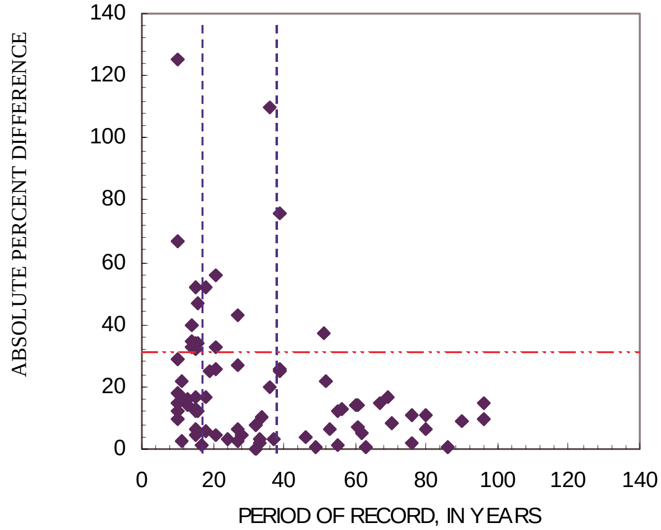

Figure 3.--Relation between the periods of record and the absolute percent differences (vertical, blue dashed lines represent 20 and 40 years of record, and horizontal red dashed line represents the median standard error of estimate for regression from Flippo,1982b)

Glossary

1-day 10-year low flow ($Q_{1,10}$), in cubic feet per second, is the average minimum streamflow expected for 1 day once every 10 years.

7-day 10-year low flow ($Q_{7,10}$), in cubic feet per second, is the average minimum streamflow expected for 7 consecutive days once every 10 years.

30-day 10-year low flow ($Q_{30,10}$), in cubic feet per second, is the average minimum streamflow expected for 30 consecutive days once every 10 years.

Climatic year is a 12-month period from April 1 to March 31.

Flow-duration table, in cubic feet per second, includes the streamflow that was equaled or exceeded for indicated percentage of time.

Harmonic mean, in cubic feet per second, is the reciprocal of the arithmetic mean of the reciprocals of a set of streamflow values for a specific period of record (Spiegel, 1961).

Mean, in cubic feet per second, is the average flow for a stream during a specific period of record.

Median, in cubic feet per second, is the flow of a stream for which there are equal numbers greater than or less than flow occurrences during a specific period of record.

Selected References

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